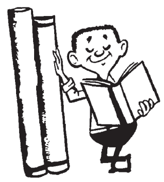
**Brayton Cycle**



Reading	**Problems**
9-8 → 9-10	9-100, 9-105, 9-131

Introduction

The gas turbine cycle is referred to as the Brayton Cycle or sometimes the Joule Cycle. The actual gas turbine cycle is an open cycle, with the intake and exhaust open to the environment.

Some examples that typically use a closed cycle version of the gas turbine cycle are:

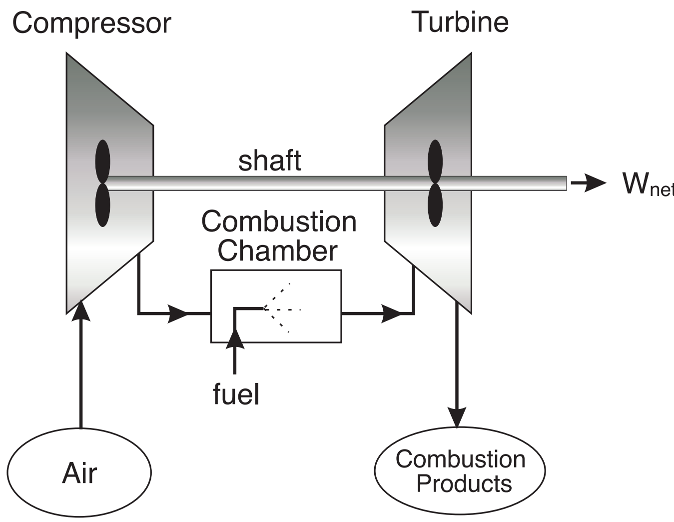
- power plants
- nuclear reactors

They generally see limited application because of the cost associated with moving a fluid with a high specific volume

Definitions

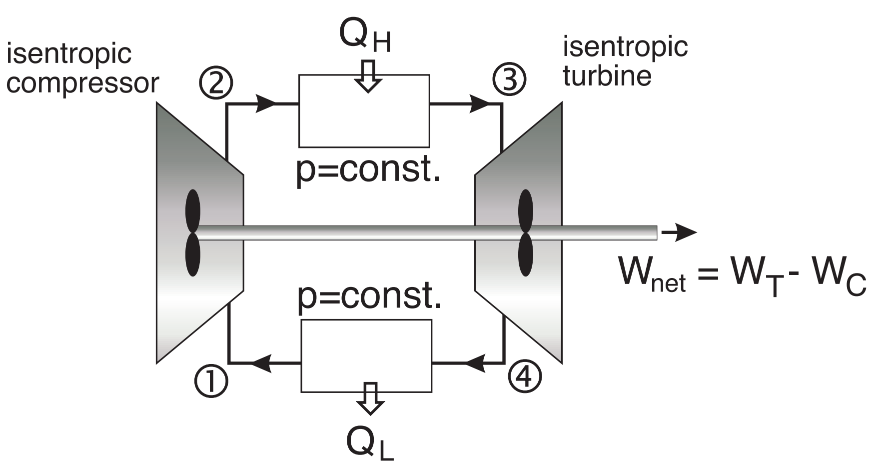
Back Work Ratio: the ratio of the compressor work to the turbine work

Open Cycle Gas Turbine Engines

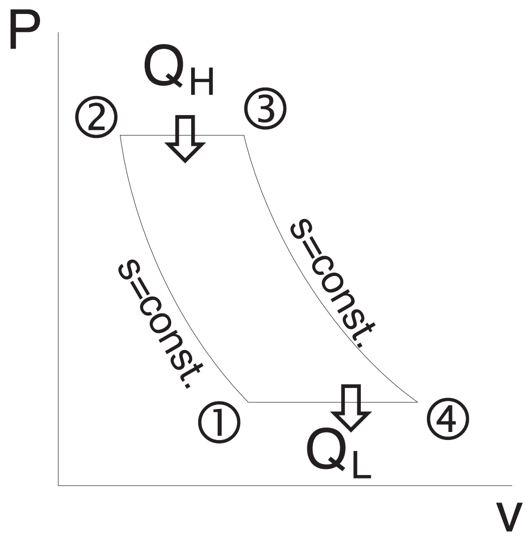


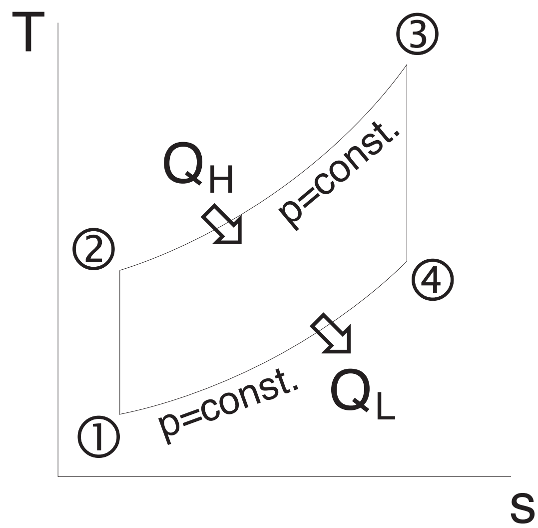
- compressor power requirements vary from 40-80% of the power output of the turbine (remainder is net power output), i.e. back work ratio = 0.4 → 0.8
- high power requirement is typical when gas is compressed because of the large specific volume of gases in comparison to that of liquids

Idealized Air Standard Brayton Cycle



- closed loop
- constant pressure heat addition and rejection
- ideal gas with constant specific heats

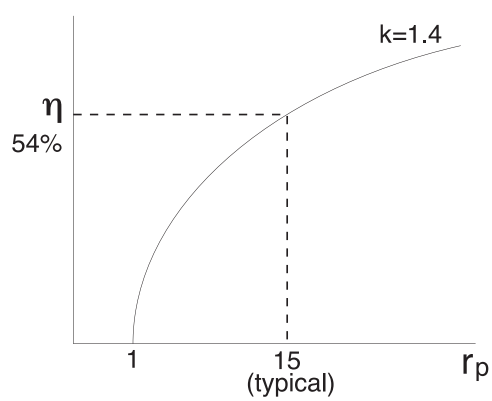




Brayton Cycle Efficiency

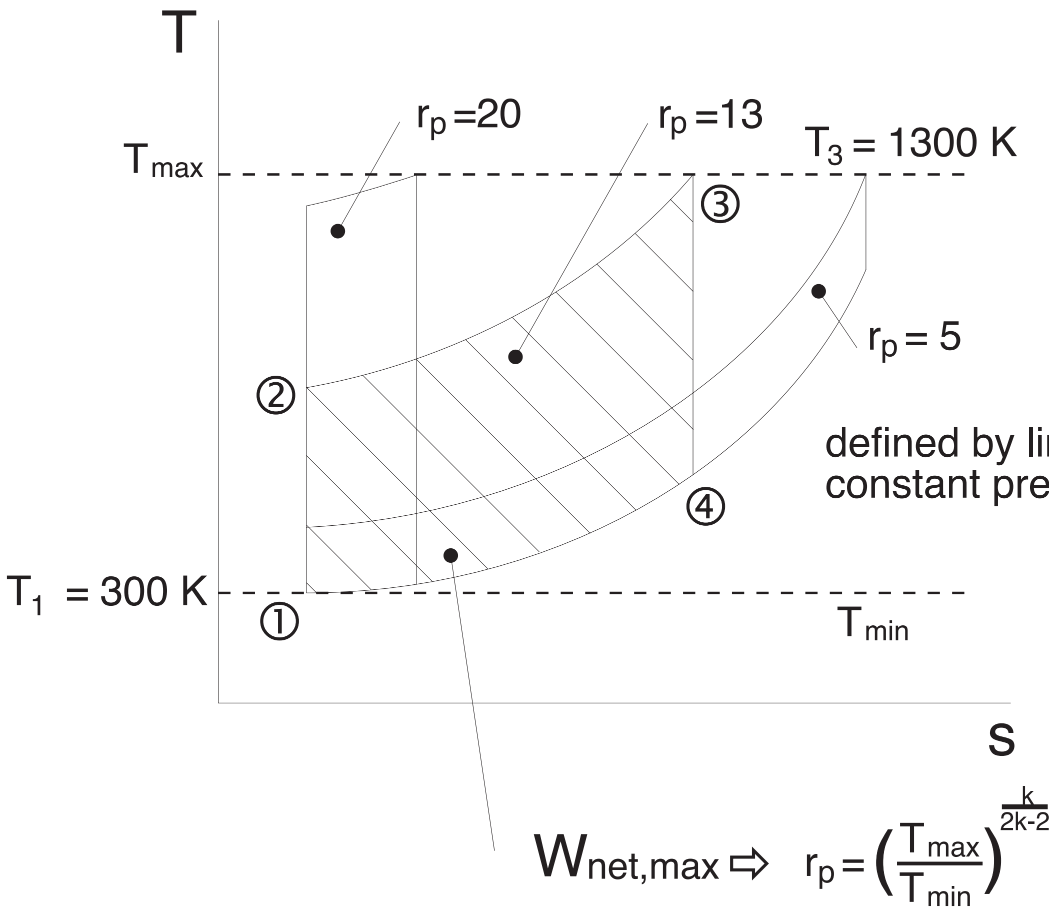
The Brayton cycle efficiency can be written as

$$\boxed{\eta = 1 - (r_p)^{(1-k)/k}}$$



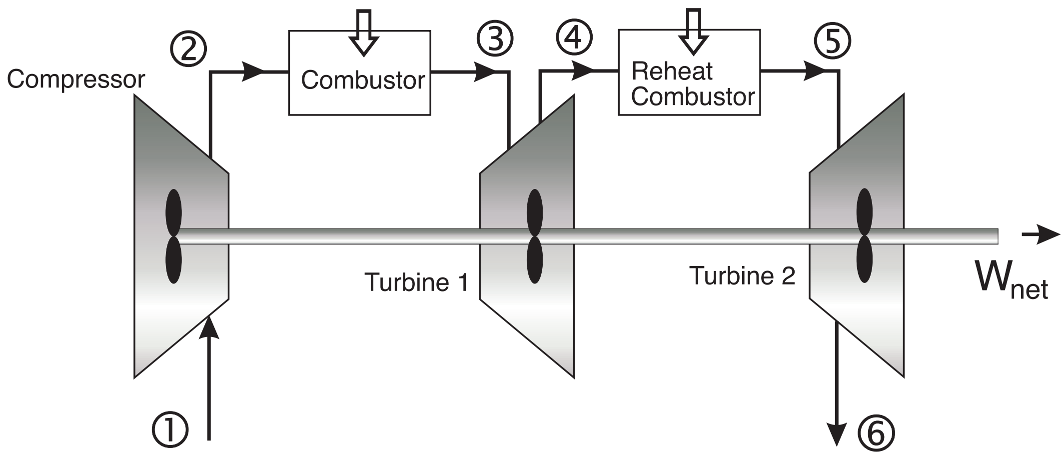
Maximum Pressure Ratio

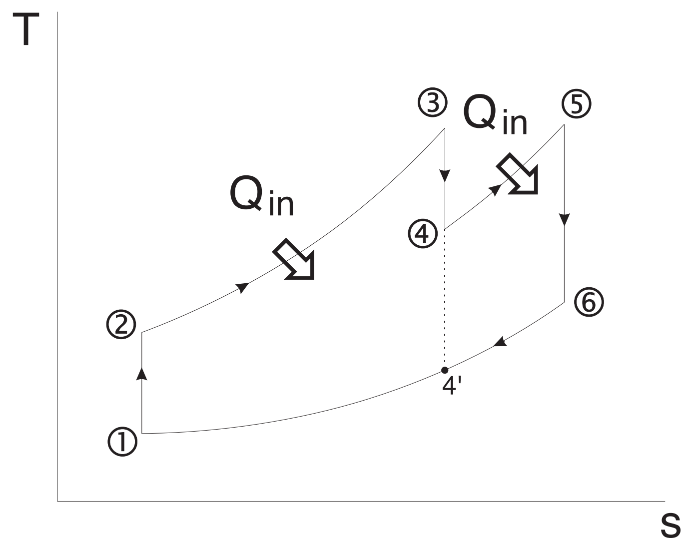
Given that the maximum and minimum temperature can be prescribed for the Brayton cycle, a change in the pressure ratio can result in a change in the work output from the cycle.



The **maximum temperature** in the cycle (T_3) is limited by metallurgical conditions because the turbine blades cannot sustain temperatures above 1300 K. Higher temperatures (up to 1600 K can be obtained with ceramic turbine blades). The **minimum temperature** is set by the air temperature at the inlet to the engine.

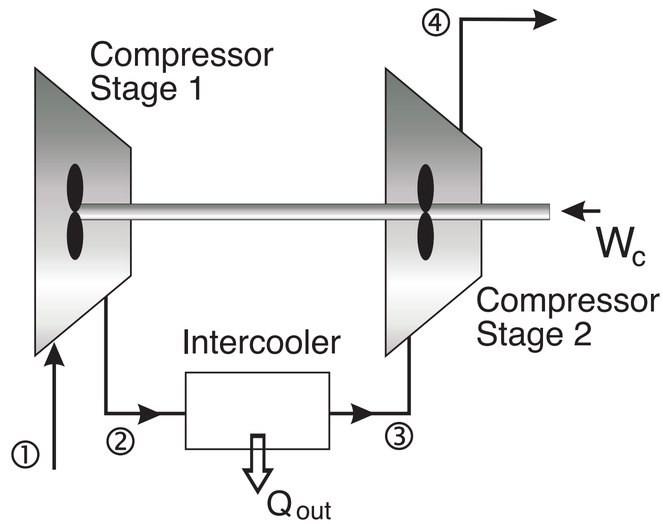
Brayton Cycle with Reheat

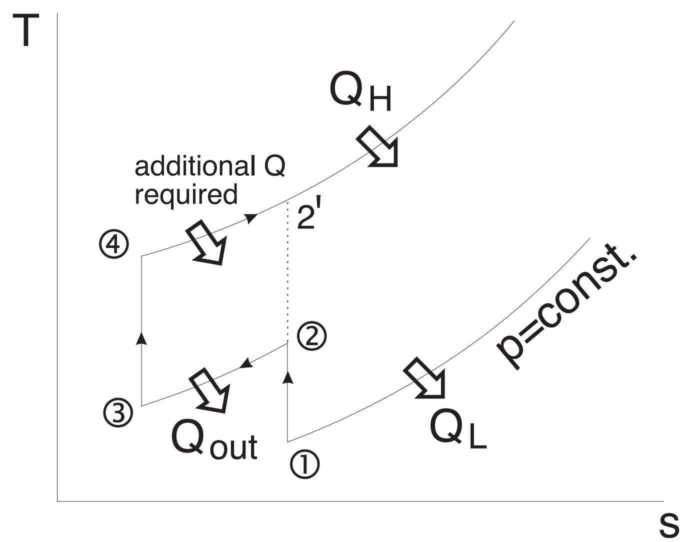




- turbine outlet temperature is increased with reheat ($T_6 > T_4'$), therefore potential for regeneration is enhanced
- when reheat and regeneration are used together the thermal efficiency can increase significantly

Compression with Intercooling





- by itself compression with intercooling does not provide a significant increase in the efficiency of a gas turbine because the temperature at the combustor inlet would require additional heat transfer to achieve the desired turbine inlet temperature
- but the lower temperature at the compressor exit enhances the potential for regeneration i.e. a larger ΔT across the heat exchanger

How Can We Improve Efficiency?

We know the efficiency of a Brayton cycle engine is given as

$$\eta = \frac{\dot{W}_{net}}{\dot{Q}_H} = \frac{\dot{W}_{turbine} - \dot{W}_{compressor}}{\dot{Q}_H}$$

There are several possibilities, for instance we could try to increase $\dot{W}_{turbine}$ or decrease $\dot{W}_{compressor}$.

Recall that for a SSSF, reversible compression or expansion

$$\frac{\dot{W}}{\dot{m}} = \int_{in}^{out} v\, dP \;\; \Rightarrow \;\; \textbf{keep } v \uparrow \textbf{ in turbine, keep } v \downarrow \textbf{ in compressor}$$

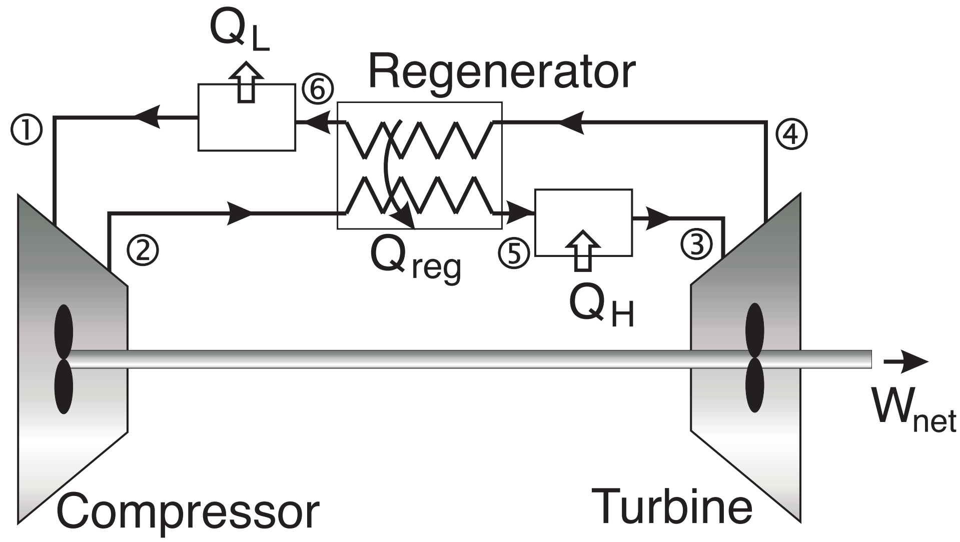
This can be achieved through the use of intercooling and reheating.

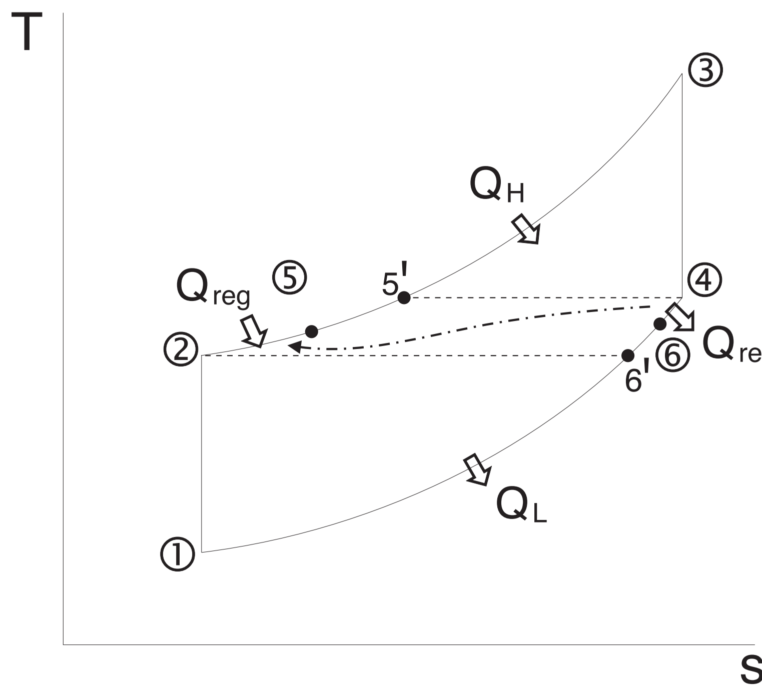
Compressor $\longrightarrow$ $\eta = \dfrac{\dot{W}_T - \dot{W}_C(\downarrow)}{\dot{Q}_{H,Total}(\uparrow)}$, overall $(\downarrow)$

Turbine $\longrightarrow$ $\eta = \dfrac{\dot{W}_T(\uparrow) - \dot{W}_C)}{\dot{Q}_{H,Total}(\uparrow)}$, overall $(\downarrow)$

The conclusion is the intercooling and/or reheating by themselves will lower η. We have to find a way to reduce $\dot{Q}_H$

Brayton Cycle with Regeneration

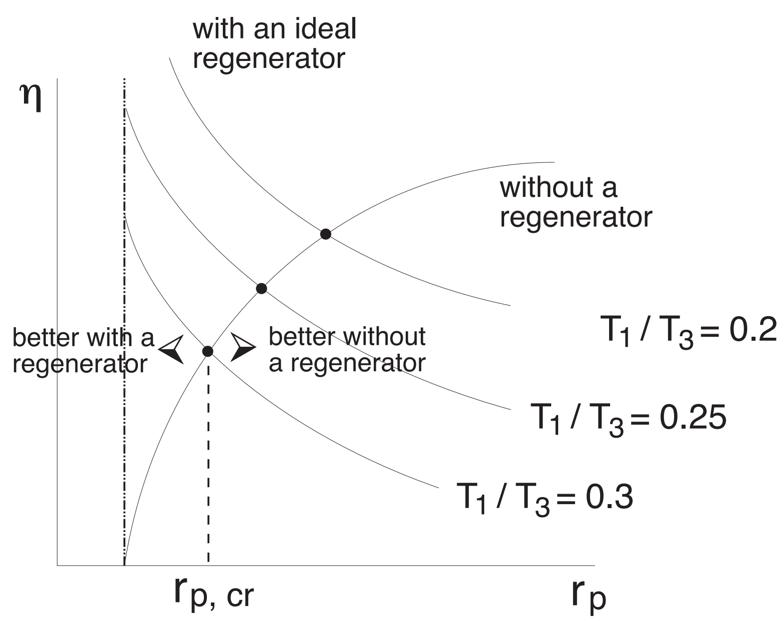




- a regenerator (heat exchanger) is used to reduce the fuel consumption to provide the required $\dot{Q}_H$

$$\boxed{\eta = 1 - \left(\frac{T_{min}}{T_{max}}\right)(r_p)^{(k-1)/k}}$$

- for a given T_{min}/T_{max}, the use of a regenerator above a certain r_p will result in a reduction of η



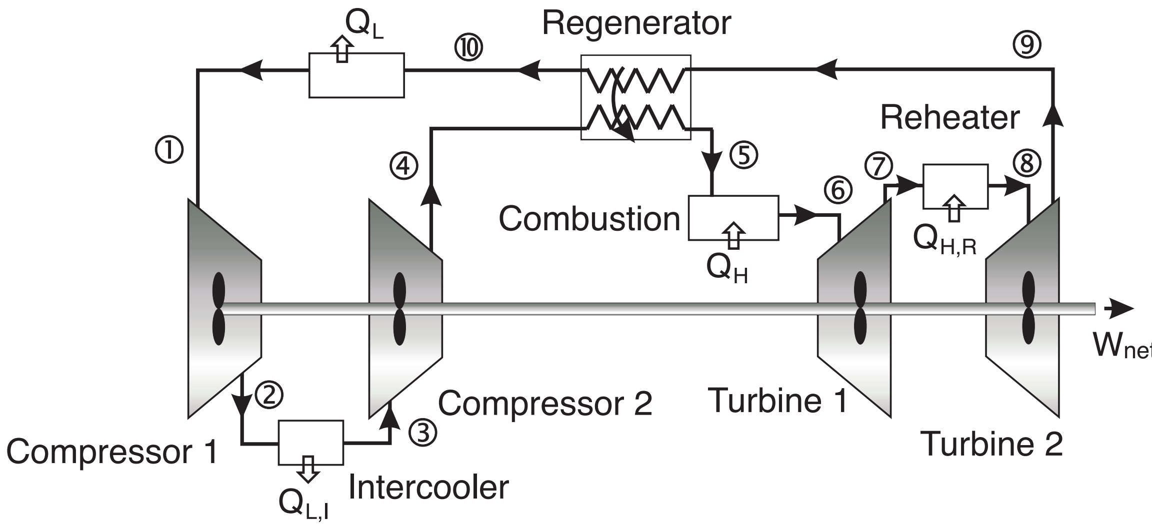
Regenerator Effectiveness

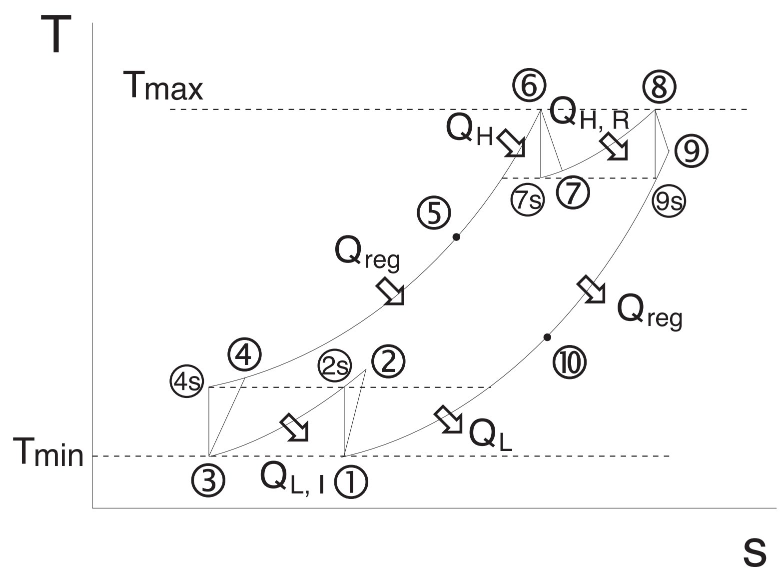
$$\epsilon = \frac{\dot{Q}_{reg,actual}}{\dot{Q}_{reg,ideal}} = \frac{h_5 - h_2}{h_5' - h_2} = \frac{h_5 - h_2}{h_4 - h_2} = \frac{T_5 - T_2}{T_4 - T_2}$$

Typical values of effectiveness are ≤ 0.7

Repeated intercooling, reheating and regeneration will provide a system that approximates the Ericsson Cycle which has Carnot efficiency $\left(\eta = 1 - \frac{T_L}{T_H}\right)$.

Brayton Cycle With Intercooling, Reheating and Regeneration





Compressor and Turbine Efficiencies

Isentropic Efficiencies

(1) $$\eta_{comp} = \frac{h_{2,s} - h_1}{h_2 - h_1} = \frac{c_p(T_{2,s} - T_1)}{c_p(T_2 - T_1)}$$

(2) $$\eta_{turb} = \frac{h_3 - h_4}{h_3 - h_{4,s}} = \frac{c_p(T_3 - T_4)}{c_p(T_3 - T_{4,s})}$$

(3) $$\eta_{cycle} = \frac{W_{net}}{Q_H} = \frac{Q_H - Q_L}{Q_H} = 1 - \frac{Q_L}{Q_H} = 1 - \frac{c_p(T_4 - T_1)}{c_p(T_3 - T_2)}$$

Given the turbine and compressor efficiencies and the maximum (T_3) and the minimum (T_1) temperatures in the process, find the cycle efficiency (η_{cycle}).

(4) Calculate T_{2s} from the isentropic relationship,

$$\frac{T_{2,s}}{T_1} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}.$$

Get T_2 from (1).

(5) Do the same for T_4 using (2) and the isentropic relationship.

(6) substitute T_2 and T_4 in (3) to find the cycle efficiency.